UNCLASSIFIED

DRES

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD

SR 635

UNCLASSIFIED

Functional Fit Evaluation to Determine Optimal Ease Requirements in Canadian Forces Chemical Protective Gloves

By:

J.F. Tremblay-Lutter
S.J. Weihrer[1]

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

[1] Kinection, Kanata, Ontario

DTIC QUALITY INSPECTED 3

November 1995

WARNING

"The use of this information is permitted subject to recognition of proprietary and patent rights."

CRAD

19980127 090

National Defence Défense nationale

Canada

UNCLASSIFIED

RESEARCH AND DEVELOPMENT BRANCH

DEPARTMENT OF NATIONAL DEFENCE

CANADA

FUNCTIONAL FIT EVALUATION TO DETERMINE OPTIMAL EASE REQUIREMENTS IN CANADIAN FORCES CHEMICAL PROTECTIVE GLOVES (U)

By

J.F. Tremblay-Lutter and S.J. Weihrer[1]

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD

DRES REPORT 635

DTIC QUALITY INSPECTED 3

1 Kinection, Kanata, Ontario

NOVEMBER 1995

ABSTRACT

A functional fit evaluation of the Canadian Forces (CF) chemical protective lightweight glove was undertaken in order to quantify the amount of ease required within the glove for optimal functional fit. The results demonstrated that a negative ease in glove digit length of 0.35 cm and a negative ease in glove digit girth of 0.19 cm provided optimal functional fit; while a positive ease of 1.75 cm in glove palm girth was optimal. It was concluded that anthropometric data should not be directly translated into glove design dimensions. Modification of the specifications from hand dimensions, which incorporates consideration of ease, must occur in order to develop gloves which enable effective function and provide a comfortable fit.

EXECUTIVE SUMMARY

A number of deficiencies have been identified with the Canadian Forces chemical protective gloves. They have inadequate POL resistance and durability; the dipping process makes them expensive to produce; they reduce hand dexterity performance; and they are impermeable to air causing sweat build-up and maceration of the hand which limits the length of time that they can be worn. In an effort to improve the Canadian Forces chemical protective gloves, DRES has been investigating new technologies for developing inexpensive, comfortable CW protective gloves with improved chemical and physical properties and improved manual performance.

To improve the dexterity properties of the gloves, computer aided design (CAD) and repeated dexterity evaluations of prototype gloves have been used to study the shape and size of a new glove form. This report describes a functional fit evaluation of the Canadian Forces chemical protective lightweight glove which was undertaken to (a) determine whether or not individuals could select a glove size which would allow them to perform optimally in fine manipulative tasks, and (b) quantify the amount of ease required within the glove for optimal functional fit and present them for use in development of glove forms for future manufacturing.

During this study, twenty-six male subjects performed dexterity tests using six different handwear conditions. The handwear conditions differed in the amount of ease they provided, whereby ease has been defined as the space provided between the surface of the hand and the inner surface of the glove. Ease was varied by having subjects use three different glove sizes which encompassed and included the glove size selected as best fitting from five available glove sizes, and having the subjects use these sizes of gloves with and without liners. This study was successful in demonstrating objective and subjective performance differences that could be attributed to differences in ease between the handwear conditions. These differences subsequently enabled identification of optimal ease values for glove design.

The results from this study demonstrated that when given the opportunity to don gloves from a range of available sizes, subjects were able to select a best fitting glove size which enabled them to perform optimally in the dexterity tasks. These results provide support for the self-selection of glove size as an effective selection method for end-users. Unlike the present approach which is to simply issue gloves to soldiers by approximation, it is important to present all available glove sizes at the time of issue to enable soldiers

to successfully select the best fitting and most functional protective glove size.

Although there are presently no liners in service to reduce the build-up of sweat inside the CF lightweight chemical protective gloves, the prototype glove liners used in this study were found to provide excellent fit and comfort and did not interfere with hand performance when worn with the best fitting chemical protective lightweight glove size.

To quantify the optimal ease required for functional protective gloves, the effects of different glove sizes on manual performance was measured. The amount of ease within the glove (handwear condition) significantly affected performance in the dexterity tests. Maximal dexterity test performance differences between the handwear conditions ranged from 15% to 34%, depending on the dexterity test. During the short-term wear scenarios of this study, moving from a selected best fitting glove to a glove that was one size smaller did not significantly enhance or degrade dexterity performance. Moving from a selected best fitting glove to a glove that was one size larger, however, significantly degraded dexterity performance.

The results from the dexterity trial were then used to calculate ease values for the new gloves. An optimal negative ease of 0.35 cm in digit length was identified for both the lined and unlined handwear conditions. This negative ease indicates that the glove digit length should be shorter than the actual digit length. As for digit girth, an optimal negative ease of 0.19 cm was identified for the **unlined** handwear conditions and thus the glove digit girth should be smaller than the actual digit girth. Finally for the palm girth, an optimal positive ease of 1.75 cm was identified for both the lined and the unlined handwear conditions. The glove palm should therefore be larger then the actual palm girth.

The results from this investigation clearly demonstrated that for the development of the final glove form, the anthropometric data should not be directly translated into glove design dimensions. Careful consideration of the Canadian Forces hand dimensions and associated ease values must take place to ensure correct modifications are made to generate optimal glove design values. Since very little data on the Canadian Forces hand dimensions are available an anthropometric survey representative of the CF soldiers was required and will be reported in another report. Since optimal ease is closely correlated to the thickness, flexibility and elongation of a polymer material, further work may be required if the final polymer for the new glove varies significantly from the in service butyl rubber glove.

TABLE OF CONTENTS

1.0 INTRODUCTION

The Defence Research Establishment Suffield (DRES) is developing an impermeable chemical protective glove specifically for tasks requiring finer hand manipulation. The basic design of the glove has proceeded through several stages of evaluation and refinement. As this design nears completion, design dimensions for various sizes of the glove must be determined. Part of this effort involves consideration of the amount of ease required within the glove to provide optimal function and comfortable fit.

Ease is operationally defined as the difference in space (i.e., length, girth, volume) between the outer surface of the hand and the inner surface of the glove. Snugness of fit and fitting tolerances are other terms that have been used in the same context as ease. Ease values provide an objective description of the fit of a glove. These values are somewhat dependent on the flexibility or suppleness of the glove material. For instance, if the glove material is highly flexible or elastic, then negative ease values may be required in order to achieve optimal function and comfort.

Numerous studies have been completed which describe the effect of wearing protective gloves on dexterity performance [1-8]. However, a recent literature search revealed very few studies that have investigated the effect of glove fit on performance [9-11] and even fewer that have attempted to identify optimal ease values for effective glove fit [12].

Glove fit has been shown to have a significant impact on performance in fine manipulative tasks. Bradley [9,10] was one of the first to show the relationship between glove fit and dexterity performance. Bradley [9] showed that a loosely fitting glove with low tenacity could be expected to increase operation time for all types of controls. Bradley [10] also collected subjective and objective performance measures on 18 different types of gloves. Significant negative correlations between snugness of fit and control operation time for 'on/off' controls and adjustable controls were found. In other words, increasing snugness of fit (decreasing ease) to an acceptable degree improved control operation time.

In another study, the effects of glove size and glove material on performance in a small parts assembly task were investigated [11]. Three sizes of cotton gloves, two sizes of smooth leather gloves and two sizes of suede leather gloves were evaluated. Significant differences in task completion time between different sizes of *some* glove types were demonstrated.

Consideration of ease was successfully applied to the development of military mittens for the Swedish Army [13]. The developmental process incorporated fit testing in order to determine fitting tolerances for critical hand dimensions.

These tolerances were applied to appropriate anthropometric hand data to derive design dimensions for the mittens. The resulting mittens were qualified as providing a "good fit" by 81% of the army personnel who evaluated them in a series of wear trials.

The fit of chemical protective gloves used by agricultural workers has also been evaluated [13]. This study investigated ease differences across various dimensions of four types of protective gloves. The amount of ease at the fingertips significantly affected dexterity performance. As the amount of ease at the tips decreased, the ability to perform dexterity tasks increased. Tremblay [13] attempted to determine optimal ease values for key dimensions by grouping estimated ease values according to whether they had been rated as providing a 'tight', 'loose' or 'just right' fit. Few differences in ease were found for the glove dimensions across these rating categories. This result was attributed to the fact that participants only used glove sizes which they had selected as best fitting; therefore, there was not an equal distribution of responses among the three rating categories. Based on these results, it was recommended that a larger number of participants, well distributed among various subjective fit rating response groups, would be needed in order to identify optimal ease values for glove design.

Several research efforts have demonstrated that there is a relationship between dexterity performance and glove fit [9-11,13]. A need has been identified for developing data on ease values for the hand which can be applied to glove design [12,13]; and a similar need has been identified for the body in general, for application to clothing design [14].

The objective of this study was to determine the amount of ease required within a chemical protective glove to enable effective function and provide a comfortable fit.

2.0 METHOD

Twenty-four male subjects performed four dexterity tests using six hand wear conditions. The subjects also completed questionnaires which addressed the fit, function and comfort of these hand wear conditions. The conditions differed in the amount of ease they provided between the surface of the hand and the inner surface of the glove. This variation in ease was achieved by having the subjects use three different glove sizes with and without a glove liner. Specific experimental details are presented in the following sections.

2.1 HAND WEAR CONDITIONS

A lightweight chemical protective glove currently in-service for the Canadian Forces (CF) was used for all hand wear conditions. This was a natural hand glove made of vulcanized chloroprene and butyl rubber. It had a thickness of 0.79 mm (31.1 mil) (measured in accordance with ASTM D 3767 Test for Rubber Thickness, procedure D) and a modulus at 100% elongation of 0.69 MPa (measured in accordance with ASTM D 412 Test for Rubber Properties in Tension). It had textured surfaces on the inner palm and on the inner and outer fingertips. The glove was available in five sizes: extra-small, small, medium, large and extra-large.

A string knit liner with a ribbed cuff was also used in the investigation. This liner was one of the many prototypes produced by Superior Glove Works (Acton, Ontario) during an investigation of glove liners for reduction of sweat build-up in polymer gloves [15]. The liner used in this study was made from a blend of cotton, viscose and lycra. It had a thickness of approximately 1 mm (39 mil). The liner was available in four sizes: small, medium, large and extra-large.

The six hand wear conditions worn by a subject were determined at the outset of the first test session. Subjects were asked to choose the size of protective glove which they felt fit them best[1] from the five available sizes. This self-selected best fitting glove size, one size larger and one size smaller were the three glove sizes used by each subject in the experiment. These three sizes were used with and without the glove liner; thus, giving the six hand wear conditions. The size of glove liner used was also a self-selected best fitting size, and this size was used consistently for all lined hand wear conditions.

2.2 SUBJECTS

Twenty-four male subjects participated in the experiment as paid volunteers. Each subject signed an informed consent form prior to participating in the investigation.

Screening for hand size was conducted prior to scheduling participants for the functional fit evaluations. Subjects were required to wear glove sizes that were smaller and larger than their self-selected best fitting size. Since only five

---

[1]The glove size they would feel most comfortable wearing for an entire day while performing a variety of activities.

glove sizes were available, only those subjects that chose a small, medium or large glove size as a best fitting size could be included in the experiment. At the time of screening, candidates were aware that only certain hand sizes would be appropriate for the testing, but they did not know which hand sizes would be accepted or rejected.

2.3 TEST PROTOCOL

During the experiment, each subject participated in two separate 4 hour testing sessions. The testing was divided into two separate sessions to minimize the effects of boredom and hand fatigue on the dexterity scores. A minimum of 24 hours separated the start of each test session for each subject. Each subject was tested individually.

During the first test session, subjects were familiarized with all aspects of the test protocol: the hand wear conditions, the hand measurements, the dexterity tests and the questionnaire. The subject selected the best fitting glove size and the best fitting liner size. Glove and liner size selections were followed by hand measurements and dexterity testing (on two of the four dexterity tests). During dexterity testing, questionnaires addressing glove fit, function and performance were completed.

The second test session was similar to the first except that the hand measurements were not repeated and the remaining two dexterity tests were completed. The same questionnaires were applied during both test sessions.

<u>Hand anthropometry</u>--The terminology used to reference basic features of the hand is presented in Figure 1.

Anthropometric measurements of the dominant hand of each subject were taken at the beginning of the first test session. The following measurements were taken while looking at the palm of the hand (palmar) or the top of the hand (dorsal):

1. hand length (wrist crease to digit 3 tip, palmar);
2. hand breadth (metacarpophalangeal, dorsal);
3. hand girth (metacarpophalangeal, dorsal);
4. wrist girth (wrist crease, palmar);
5. digit lengths (from middle of finger base line digit crease to middle of digit tip, palmar);

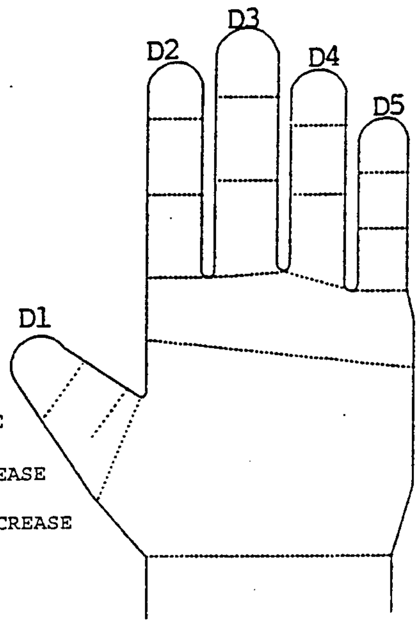


FIG. 1: Terminology for basic hand features.

6. palm length (wrist crease to middle of digit 3 finger base line crease, palmar);

7. upper palm length (lower thenar crease to side of proximal digit 2 crease, palmar);

8. digit girth (at proximal crease for digits 2 through 5, and distal crease for digit 1, palmar);

9. digit 1 maximal girth (at lower thenar crease, palmar); and

10. hand volume.

All girth measurements were taken with a metal measuring tape. All length and breadth measurements were taken with dial callipers. The volume of the dominant hand was measured by determining the volume of water displaced from a flask, upon immersion of the hand to the level of the wrist crease.

Measurement error sources for hand anthropometry included landmark identification, hand position during measurement, pressure applied during measurement, and measurement reading and recording. Great care was taken to reduce the magnitude of these measurement error sources. Only one researcher collected the hand dimension data; therefore, hand posture, landmarking and level of pressure applied during measurement, were quite consistent between subjects. In order to reduce the possibility of measurement reading and recording errors, two complete rounds of hand measurements were performed for each subject. Measurements for a given subject were repeated if differences between these two rounds were greater than 1 mm for lengths, breadths and girths; or greater than 5 mL for hand volume. The absolute value of difference between these two rounds of measurements were tabulated for each subject in order to determine measurement error values. The mean absolute error values were consistently below 1 mm for the length, breadth and circumference dimensions; and the mean for hand volume was below 3 mL.

Manual dexterity tests--Objective measures of the effect of glove fit on performance in fine manipulative tasks were obtained using four tests of manual dexterity: the Minnesota Rate of Manipulation Turning Test [16], the O'Connor Fine Finger Dexterity Test, the Cord Manipulation and Cylinder Stringing Test [3], and the Magazine Loading Test [17]. Completion times were used as the performance measures for all dexterity tests. Detailed descriptions of the procedures used for the dexterity testing have been presented in an earlier report [17].

The Minnesota and O'Connor Tests were always completed during the first test session. The Cord and Magazine Tests were always completed during the second test session.

Subjects were given several practise trials to ensure that learning for each dexterity test was essentially complete before any actual trials were performed [18]. Eight practise trials were performed for each dexterity test. Two barehanded practise trials were completed; these were followed by one practise trial in each of the six hand wear conditions. During practise the hand wear conditions were always presented in the following order: unlined best fitting size, unlined smaller size, unlined larger size, lined best fitting size, lined smaller size and lined larger size.

Following completion of all practise trials for both dexterity tests performed on a test day, subjects completed sets of three actual trials for each hand wear condition. These sets were randomized for hand wear condition and dexterity test. This type of randomization has been suggested to reducing effects due to boredom, muscular fatigue and residual learning [18]. The first of the three actual trials in a set was used to re-acquaint the subject with the test. The mean of the second and third trials was used as the score for the test.

Questionnaire--A questionnaire consisting of 19 questions was used to gather subjective information on the fit, function and comfort of each hand wear condition (Annex A). The questionnaire for a particular hand wear condition was administered immediately after completion of the final dexterity trial for that hand wear condition (while the subject was still wearing the glove).

2.4 POLYMER GLOVE MEASUREMENTS

Outer glove dimensions were measured, prior to the dexterity trials, on a sample of 40 of the actual gloves used in the functional fit evaluation. This sample was comprised of eight gloves from each size category -- four right hand gloves and four left hand gloves. The following eleven dimensions were measured on the protective gloves:

1. palm girth (1 cm below crotch 4);
2. digit lengths (from mid-point of line drawn across glove digit crotches to center of glove digit tip, parallel to long axis of digit);
3. digit girth (at estimated proximal crease position);
4. glove thickness (ASTM D 3767, procedure D); and
5. glove volume (estimated from the volume of the porcelain lasts (hand forms used to produce the gloves) by measuring the volume of water displaced when the last was immersed to the level of the wrist crease).

2.5 EASE CALCULATIONS

A total of twelve ease values were calculated for each hand wear condition: hand volume ease, palm girth ease, digit girth ease for all five digits and digit length ease for all five digits. The first step in calculating the ease values was to convert the measured outer glove dimensions to inner glove dimensions; that is, to correct for the thickness of the glove. The second step was to account for the thickness of the liner for the three lined hand wear conditions. In general, ease values were calculated by subtracting the hand dimension from the inner glove dimension. A detailed account of the assumptions, methods and equations used to calculate these ease values has been presented in an earlier report [17].

3.0 RESULTS & DISCUSSION

3.1 SUBJECTS

Descriptive statistics for the general characteristics of the subjects are presented in Table 1. As the data in the table reveal, the subjects demonstrated a wide range of hand dimensions. T-test comparisons of this group with the summary statistics from two CF anthropometric surveys [19,20] confirmed that the subjects involved in the functional fit evaluation were representative of the CF male population (Table 1).

TABLE 1 --General characteristics of subject sample and comparison with CF surveys

		1992 Functional Fit Study (n=24)		1985 CF Aircrew Survey [19] (n=519)		1974 CF Survey [18] (n=565)	
	Age (years)	Hand Length (cm)	Hand Breadth (cm)	Hand Length (cm)	Hand Breadth (cm)	Hand Length (cm)	Hand Breadth (cm)
Mean	22	19.38	8.84	19.25	8.70	19.20	8.91
SD	5	0.90	0.41	0.87	0.39	0.88	0.45
Min	18	17.28	8.03	17.20	7.70	-	-
Max	33	20.90	10.03	22.30	9.90	-	-

3.2 GLOVE SIZE SELECTION

Ten of the twenty-four subjects selected the medium size of the protective glove as a best fitting glove size; seven subjects selected the large size as best fitting; and seven subjects selected the small size as best fitting. Protective glove size selection was fairly well correlated to hand anthropometry. The highest correlation coefficients were obtained for: hand length (r=0.80), palm length (r=0.78), digit 2 length (r=0.75) and hand volume (r=0.73).

Liner size selection was also correlated to hand anthropometry, but not to the same degree as glove size selection. The fit of the liner in the crotches and the tips of the fingers appeared to be the most important consideration in size selection. This observation was supported by the fact that the lengths of digit 2 through digit 5 were the most highly correlated to the best fitting liner size, with correlation coefficients of 0.66, 0.62, 0.63 and 0.61, respectively.

3.3 EASE

Outer glove dimensions were translated to inner glove dimensions by compensating for the thickness of the glove and the liner, where appropriate [17]. Twelve ease values were calculated for each hand wear condition by comparing the inner glove dimensions to each subject's hand dimensions. Mean ease values across the six hand wear conditions are presented in Table 2.

TABLE 2--Mean ease values in cm (n=24)

	Hand Wear Condition					
Ease Dimension	Unlined			Lined		
	Smaller	Best	Larger	Smaller	Best	Larger
Volume (mL)	48.70^{B}	113.60^{C}	169.10^{D}	1.70^{A}	66.60^{B}	122.10^{C}
Dig 1 Length	-0.49^{A}	-0.16^{B}	0.20^{C}	-0.49^{A}	-0.16^{B}	0.20^{C}
Dig 2 Length	-0.41^{A}	-0.12^{B}	0.24^{C}	-0.41^{A}	-0.12^{B}	0.24^{C}
Dig 3 Length	-0.47^{A}	-0.24^{B}	0.20^{C}	-0.47^{A}	-0.24^{B}	0.20^{C}
Dig 4 Length	-0.32^{A}	-0.05^{B}	0.26^{C}	-0.32^{A}	-0.05^{B}	0.26^{C}
Dig 5 Length	-0.31^{A}	-0.01^{B}	0.37^{C}	-0.31^{A}	-0.01^{B}	0.37^{C}
Dig 1 Girth	-0.19^{C}	-0.03^{D}	0.08^{D}	-0.82^{A}	-0.66^{B}	-0.54^{B}
Dig 2 Girth	-0.66^{C}	-0.49^{D}	-0.15^{E}	-1.29^{A}	-1.12^{B}	-0.78^{C}
Dig 3 Girth	-0.25^{D}	-0.14^{E}	-0.04^{F}	-0.88^{A}	-0.77^{B}	-0.67^{C}
Dig 4 Girth	0.04^{D}	0.30^{E}	0.47^{F}	-0.59^{A}	-0.33^{B}	-0.16^{C}
Dig 5 Girth	-0.02^{C}	0.32^{D}	0.54^{E}	-0.64^{A}	-0.31^{B}	-0.09^{C}
Palm Girth	1.16^{B}	2.35^{D}	3.68^{F}	0.53^{A}	1.73^{C}	3.05^{E}

Means with the same superscript letter are not significantly different (.05)

A one-way analysis of variance was performed for each ease dimension in order to determine whether or not significant differences in ease were achieved by manipulating the glove size worn. The results demonstrated that, for all ease dimensions, the hand wear conditions had a significant effect on ease. Duncan's mean comparison test was applied for each ease dimension, to determine between which conditions there were significant differences [21]. The results from these analyses have been included in Table 2 by entering a letter code above each mean value. Ease values for a given dimension are **not** significantly different if they have the same letter code superscript.

Statistically significant differences in ease were apparent between the hand wear conditions. For all ease dimensions, except digit 1 girth ease, differences in ease between best, smaller and larger conditions were significant. These results demonstrate that the six hand wear conditions were effective in significantly modifying the level of ease provided within the glove. The next step was to determine whether or not these changes in ease affected performance in the dexterity tests.

3.4 DEXTERITY TEST RESULTS

In order to investigate the effect of hand wear condition on manual dexterity performance, general linear models (GLM) analyses of variance -- using a Completely Randomized Block (CRB) approach with subjects as the blocking factor -- were applied to the dexterity test completion times [21]. The results from these analyses revealed that there were significant main effects due to hand wear condition for all four dexterity tests. The results from subsequent mean comparisons tests are presented in Table 3.

The effect of glove size on test completion time appears to have been dramatic for some dexterity tests and only moderate for others. Differences in fastest and slowest mean completion times ranged from 6.73 s in the Minnesota test to 43.58 s in the Cord test. In general, dexterity performance across the tests was consistently better when either the unlined smaller fitting or the unlined best fitting hand wear conditions were worn. There were **never** significant differences in performance times between these two conditions. Therefore, moving from a selected best fitting unlined glove to a tighter fitting unlined glove did not significantly enhance or degrade dexterity performance. On the other hand, moving from a selected best fitting unlined glove to a larger fitting unlined glove resulted in significant increases in

TABLE 3--Mean dexterity test completion time in seconds across hand wear conditions (n=24)

Test	Hand Wear Condition: Unlined			Lined		
	Smaller	Best	Larger	Smaller	Best	Larger
Minnesota						
X	43.93^{A}	$45.79^{A,B}$	$50.12^{C,D}$	$48.07^{B,C,D}$	$47.61^{B,C}$	50.66^{D}
SD	6.09	7.82	9.39	7.02	7.30	9.73
O'Connor						
X	82.93^{A}	$85.11^{A,B}$	$90.92^{B,C}$	91.51^{C}	92.22^{C}	99.50^{D}
SD	10.53	11.99	19.46	15.65	15.52	22.96
Cord						
X	84.01^{A}	92.44^{A}	$113.75^{B,C}$	90.44^{A}	$102.17^{A,B}$	127.59^{C}
SD	22.57	26.03	36.52	21.50	24.26	41.76
Magazine						
X	62.66^{A}	$64.71^{A,B}$	67.61^{B}	$64.76^{A,B}$	67.60^{B}	72.22^{C}
SD	11.91	10.69	12.14	11.47	14.41	13.16

Means with the same superscript letter are not significantly different (.05)

performance time for the Minnesota and Cord tests.

The liner did not degrade performance to the extent that was anticipated. When the performance times for the lined gloves were compared to those of the same size of unlined gloves, then only for the O'Connor test did the liner have a consistently significant degrading effect on performance. This finding was in agreement with Bradley's [9-10] findings in that increasing snugness of fit to an acceptable degree improves the performance rate for some hand manipulation tasks.

Performance with the lined larger hand wear condition consistently resulted in the slowest dexterity test completion times. Whereas, performance with the lined smaller condition was comparable to performance with the unlined best fitting size for the Minnesota, Cord and Magazine tests. Therefore, it appears that increased ease, compared to the ease provided it appears that increased ease, compared to the ease provided by the self-selected best fitting glove, imposed a greater performance decrement than decreased ease, whether that decreased ease was the result of using a smaller glove size or wearing a liner. It should be noted that each hand wear condition was only worn for approximately 14 minutes. Therefore, these results reflect a short-term wear scenario; that is, the effect of wearing a tighter fitting glove versus a looser fitting glove for an extended duration was not evaluated. Further evaluations would be required to determine the long-term effect of wearing snug-fitting gloves.

The dexterity results also demonstrated that the subjects were able to select a glove size which allowed them to perform optimally in the dexterity tests -- when they were given the range of glove sizes to choose from. These results provide support for a simple method of establishing the size of glove that an individual can effectively wear -- that is, self-selection. This method is attractive because it does not require measurement of key dimensions nor does it require the use of a sizing template. It also incorporates consideration of comfort -- a highly variable component in glove sizing.

3.5 QUESTIONNAIRE RESULTS

Questionnaires were incorporated into the functional fit evaluation to gather subjective information on the fit, function and comfort of the six hand wear conditions. A lengthy discussion of the questionnaire responses for each hand wear condition has been presented in a previous report [17]. In general, analyses of the subjective data revealed that perceived fit was closest to optimal for the unlined and the lined best fitting gloves, as well as for the unlined and the lined smaller fitting gloves. Conversely, subjects generally indicated that fit was furthest from optimal when either of the larger hand wear conditions were worn.

The results from both the objective and subjective components of the functional fit evaluation corresponded very well. Subjects were able to perform optimally in the dexterity tasks with the best fitting glove and the smaller fitting glove. In addition, subjects indicated that these hand wear conditions generally fit better than the others. It follows that some combination of the ease values associated with the unlined best fitting and smaller fitting gloves would result in acceptable and effective glove fit.

3.6 OPTIMAL EASE VALUES FOR GLOVE DESIGN

Optimal ease values were established by identifying the hand wear condition which received optimal subjective ratings and by using the ease values associated with those hand wear conditions. It was possible to use the subjective fit ratings in this manner because of the strong agreement between the subjective and objective fit testing results. Ease values were identified for digit length, digit girth and palm girth. It should be noted, however, that depending on the thickness, flexiblity and elongation of a polymer glove material, recommended ease values would differ. The ease values presented here are recommended for gloves with similar physical properties as the Canadian Forces butyl rubber glove.

Ease values for digit length--To reflect the best performance times, optimal digit length ease values across digit one through digit five were determined by averaging the ease associated with these digits in the best fitting and smaller fitting gloves. The resulting mean ease values for digit one through five were as follows: -0.49 cm, -0.27 cm, -0.36 cm, -0.32 cm and -0.31 cm, respectively. All of the digit length ease values were negative. This negative ease indicates that, for a protective glove with physical properties similar to the CF chemical protective glove, glove digit length should be shorter than anthropometric digit length. The intuitive practice of reducing glove digit length to ensure good glove fingertip fit [22] is supported by the results of this investigation.

Because of the preliminary nature of this work, it is recommended that a conservative approach be used in applying these ease values to glove design. A constant digit length ease value should be applied across all digits. This value is best represented as the average of the five digit length ease values indicated as optimal based on the objective and subjective test results: -0.35 cm.

Ease values for digit girth--The subjective ratings of glove fit and the values for digit girth ease did not correspond well. The estimated level of ease in digit girth for the lined conditions seemed much lower (less room within the glove) than the subjective fit ratings suggest. The most obvious cause of this inconsistency was the method used to account for the liner in the calculation of ease girth. A relaxed liner thickness of 1 mm was used in all calculations. When the liner was worn it was stretched well beyond a relaxed state. Therefore, the actual thickness of the liner when worn would have been less than 1 mm. While this was obvious from the outset of the study, the complexities involved in obtaining a realistic liner thickness were beyond the scope of this investigation. It was hoped that by applying a constant factor, changes across hand wear conditions would be correct in a relative sense. It appears, however, that for small dimensions, such as digit girth, the errors incurred by assuming a 1 mm liner thickness resulted in obvious underestimation of digit girth ease for the lined hand wear conditions (Table 2).

On the other hand, the digit girth ease values for the unlined hand wear conditions corresponded well with the digit girth fit ratings. The direction of change was similar for both variables, as was the level of significant difference between the conditions. Because the validity of the digit girth ease values was questionable for the lined hand wear conditions, only the girth ease values of the unlined hand wear conditions were used to establish optimal digit girth ease values for glove design. Optimal digit girth ease values across digit 1 through digit 5 for unlined gloves were: -0.19 cm, -0.58 cm, -0.20 cm, +0.04 cm, and -0.02 cm, respectively.

These individual digit girth ease values are not as consistent as the individual digit length ease values, which were all negative and had a small range of 0.22 cm. The girth ease for digit 2 appears to be disproportionately small in comparison to the girth ease values for the other digits. The range of girth ease for the digits would be only 0.24 cm if digit 2 was not considered, instead of 0.62 cm. Whether this is a 'real' difference in individual digit girth ease requirements based on the critical activity of the index finger in most dexterity tasks, or whether this result is anomalous is unknown. However, because of the preliminary nature of the work, it is again recommended that a conservative approach be used in applying these girth ease values to glove design. A constant digit girth ease value should be applied across all digits. This value is best represented as the average of the five digit girth ease values indicated as optimal based on the objective and subjective test results: -0.19 cm. The negative girth ease indicates that the glove digit girth should be smaller than the actual digit girth.

Ease values for palm girth--The ratings of palm girth fit and the palm girth ease values corresponded very well. With each increase in palm girth ease, the subjective rating of palm girth fit increased proportionately. Therefore, the effect of the liner on the palm girth ease values appears valid. The hand wear conditions which involved the liner received palm girth fit ratings which were consistently one-half unit below those of the same glove size worn without a liner. With palm girth being almost 3.5 times as large as the digit girth dimension, it is likely that the inaccuracy of using a relaxed liner thickness in the calculation of palm girth ease for the lined hand wear conditions was not significant.

Optimal subjective ratings of palm girth fit were received by the unlined smaller glove, and the unlined and lined best fitting gloves. Once again, it is recommended that the average ease value of +1.75 cm for these conditions be applied as a palm girth ease requirement for unlined and lined gloves.

4.0 CONCLUSIONS

The results of this investigation clearly demonstrate that anthropometric data should not be directly translated into glove design dimensions. From a user population's representative hand dimensions, modification must be made to develop the final dimensions of gloves which enable effective performance in fine manipulative tasks and which provide a comfortable fit.

In summary, the following ease values have been identified for lined and unlined protective gloves that have physical characteristics similar to the CF chemical protective glove:

1. a digit length ease, for unlined and lined gloves, of -0.35 ± cm;

2. a digit girth ease, for unlined gloves only, of -0.19 ± cm; and

3. a palm girth ease, for unlined and lined gloves, of +1.75 ± cm.

The ease values determined in this study serve as an important starting point in the process of providing glove designers with concrete figures to apply to anthropometric measures of the hand in order to develop glove design dimensions. Research efforts along these lines should continue, with the ultimate goal being to develop a complete profile of ease requirements for a variety of protective gloves in both short-term and long-term wear scenarios.

5.0 REFERENCES

1. Bensel, C. K., "A human factors evaluation of two types of rubber CB protective gloves," Technical Report Natick/TR-80/005, United States Army Natick, Natick, Massachusetts, 1980.

2. Cattroll, S. W., "Dexterity comparison between Canadian and French CW gloves," DREO Technical Note 82-36, Defence Research Establishment Ottawa, Ottawa, Canada, 1983.

3. McGinnis, J. M., Bensel, C. K., and Lockhart, J. M., "Dexterity afforded by CB protective gloves," Technical Report 73-35-PR, United States Army Natick, Natick, Massachusetts, 1973.

4. Robinette, K. M., Ervin, C., and Zehner, G. F., "Dexterity testing of chemical defense gloves (U)," AAMRL-TR-86-021, Wright Patterson Air Force Base, Ohio, 1986.

5. Ross, J. and Ervin, C., "Chemical defense flight glove ensemble evaluation (U)," AAMRL-TR-87-047, Wright Patterson Air Force Base, Ohio, 1987.

6. Teixeira, R. A. and Bensel, C. K., "The effects of chemical protective gloves and glove liners on manual dexterity (U)," NATICK/TR/91/002, U.S. Army Natick Research, Development and Engineering Center, Natick, Massachusetts, 1990.

7. Vittorio, P. V., Nolan, R. W., and Cattroll, S. W., "Dexterity afforded by experimental CW protective gloves," DREO Technical Note 76-2, Defence Research Establishment Ottawa, Ottawa, Canada, 1976.

8. Weihrer, S. and Rhodes, W., "Degradation in manual dexterity tasks attributable to the new concept NBC protective glove," DREO/PSD/CPS Contractor Report No.: 12/91, Defence Research Establishment Ottawa, Ottawa, Canada, 1991.

9. Bradley, J. V., "Effect of gloves on control operation time," Human Factors, Vol. 11, No. 1, 1969, pp. 13-20.

10. Bradley, J. V., "Glove characteristics influencing control manipulability," Human Factors, Vol. 11, No. 1, 1969, pp. 21-36.

11. Chen, Y., Cochran, D. J., and Bishu, R. R., "Glove size and material effects on task performance," Proceedings of the Human Factors Society 33rd Annual Meeting - 1989, 1989, pp. 708-712.

12. Tremblay, J. F., "Evaluation of functional fit and comfort of chemical protective gloves for agricultural workers," Master's thesis, University of Alberta, Edmonton, Canada, 1989.

13. Rosenblad-Wallin, E., "An anthropometric study as the basis of sizing anatomically designed mittens," Applied Ergonomics, Vol. 18, No. 4, 1987, pp. 329-333.

14. Gordon, C. C., "Anthropometric sizing and fit testing of a single battledress uniform for U.S. Army men and women," Performance of Protective Clothing, ASTM STP 900, R. L. Barker and G. C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, 1986, pp. 581-592.

15. Tremblay-Lutter, J. F., Lang, J. Q. and Pichette, D., "Evaluation of Candidate glove liners for reduction of skin maceration in impermeable protective gloves," Performance of Protective Clothing, ASTM STP 1237, J. S. Johnson and S. Z. Mansdorf, Eds., American Society for Testing and Materials, Philadelphia, 1995.

16. Betts, L., (Ed), "Minnesota Rate of Manipulation Test Examiner's Manual," Educational Test Bureau, Educational Publishers, Minneapolis, 1946.

17. Weihrer, S. and Rhodes, W., "Functional fit evaluation of Canadian Forces protective lightweight glove," DREO/PSD/CPS Contractor Report No.: 02/92, Defence Research Establishment Ottawa, Ottawa, Canada, 1992.

18. Ervin, C., "A standardized dexterity test battery," Mansdorf, R. S., and P. P. Nielson, Eds., Performance of protective clothing: Second symposium, ASTM STP 989, American Society for Testing and Materials, Philadelphia, Philadelphia, 1988, pp. 50-56.

19. McCann, C., Noy, I., Rodden, B., and Logan, O., "1974 Anthropometric survey of Canadian Forces personnel," Report No. 75-R-1114, Defence and Civil Institute of Environmental Medicine, Downsview, Canada, 1975.

20. Stewart, L. E., "1985 Anthropometric survey of Canadian Forces aircrew," Technical Report No. 85-12-01, Defence and Civil Institute of Environmental Medicine, Downsview, Canada, 1985.

21. Hintze, J. L. (1991). Number Cruncher Statistical System Version 5.03 9/91. Dr. J. L. Hintze, Kaysville, Utah.

22. Kennedy, S. J., Woodbury, R. L., and Madnick, H., "Design and development of natural hand gloves," Series Report No. 33, United States Army Natick, Clothing and Equipment Development Branch, Natick, Massachusetts, 1962.

ANNEX A

GLOVE: ____________________

ID #: ____________________

DATE: ____________________

FUNCTIONAL FIT QUESTIONNAIRE

GLOVE

Rate the fit of the glove in the following areas of the hand by circling the number along the scale that corresponds to the most appropriate response.

1. OVERALL FIT:

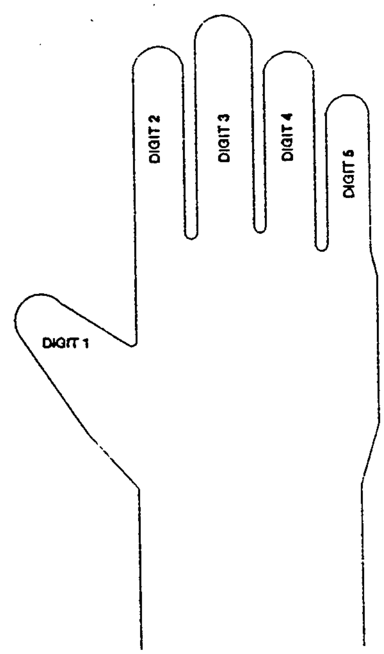
--------1-------------2-------------3-------------4-------------5--------

1	2	3	4	5
VERY GOOD	GOOD	NEITHER GOOD NOR POOR	POOR	VERY POOR

2. DIGIT 1 LENGTH:

--------1-------------2-------------3-------------4-------------5--------

1	2	3	4	5
TOO LONG	TOO LONG BUT ACCEPTABLE	JUST RIGHT	TOO SHORT BUT ACCEPTABLE	TOO SHORT



3. DIGIT 2 LENGTH:

--------1-------------2-------------3-------------4-------------5--------

1	2	3	4	5
TOO LONG	TOO LONG BUT ACCEPTABLE	JUST RIGHT	TOO SHORT BUT ACCEPTABLE	TOO SHORT

4. DIGIT 3 LENGTH:

--------1-------------2-------------3-------------4-------------5--------

1	2	3	4	5
TOO LONG	TOO LONG BUT ACCEPTABLE	JUST RIGHT	TOO SHORT BUT ACCEPTABLE	TOO SHORT

5. DIGIT 4 LENGTH:

--------1-------------2-------------3-------------4-------------5--------

1	2	3	4	5
TOO LONG	TOO LONG BUT ACCEPTABLE	JUST RIGHT	TOO SHORT BUT ACCEPTABLE	TOO SHORT

6. DIGIT 5 LENGTH:

--------1-------------2-------------3-------------4-------------5--------

1	2	3	4	5
TOO LONG	TOO LONG BUT ACCEPTABLE	JUST RIGHT	TOO SHORT BUT ACCEPTABLE	TOO SHORT

7. DIGIT 1 CIRCUMFERENCE:

--------1-------------2-------------3-------------4-------------5--------

TOO LOOSE	TOO LOOSE BUT ACCEPTABLE	JUST RIGHT	TOO TIGHT BUT ACCEPTABLE	TOO TIGHT

8. DIGIT 2 CIRCUMFERENCE:

--------1-------------2-------------3-------------4-------------5--------

TOO LOOSE	TOO LOOSE BUT ACCEPTABLE	JUST RIGHT	TOO TIGHT BUT ACCEPTABLE	TOO TIGHT

9. DIGIT 3 CIRCUMFERENCE:

--------1-------------2-------------3-------------4-------------5--------

TOO LOOSE	TOO LOOSE BUT ACCEPTABLE	JUST RIGHT	TOO TIGHT BUT ACCEPTABLE	TOO TIGHT

10. DIGIT 4 CIRCUMFERENCE:

--------1-------------2-------------3-------------4-------------5--------

TOO LOOSE	TOO LOOSE BUT ACCEPTABLE	JUST RIGHT	TOO TIGHT BUT ACCEPTABLE	TOO TIGHT

11. DIGIT 5 CIRCUMFERENCE:

--------1-------------2-------------3-------------4-------------5--------

TOO LOOSE	TOO LOOSE BUT ACCEPTABLE	JUST RIGHT	TOO TIGHT BUT ACCEPTABLE	TOO TIGHT

12. PALM CIRCUMFERENCE:

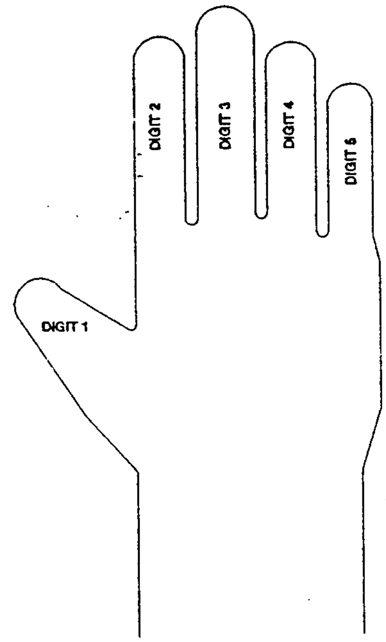
--------1-------------2-------------3-------------4-------------5--------

TOO LOOSE	TOO LOOSE BUT ACCEPTABLE	JUST RIGHT	TOO TIGHT BUT ACCEPTABLE	TOO TIGHT

13. WRIST CIRCUMFERENCE:

--------1-------------2-------------3-------------4-------------5--------

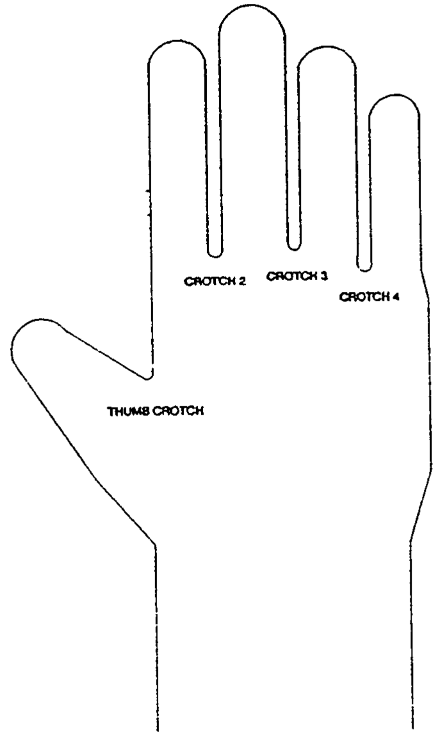
TOO LOOSE	TOO LOOSE BUT ACCEPTABLE	JUST RIGHT	TOO TIGHT BUT ACCEPTABLE	TOO TIGHT



14. CROTCH OF THUMB:

--------1------------2------------3------------4------------5--------

TOO HIGH	TOO HIGH BUT ACCEPTABLE	JUST RIGHT	TOO LOW BUT ACCEPTABLE	TOO LOW



15. CROTCH 2:

--------1------------2------------3------------4------------5--------

TOO HIGH	TOO HIGH BUT ACCEPTABLE	JUST RIGHT	TOO LOW BUT ACCEPTABLE	TOO LOW

16. CROTCH 3:

--------1------------2------------3------------4------------5--------

TOO HIGH	TOO HIGH BUT ACCEPTABLE	JUST RIGHT	TOO LOW BUT ACCEPTABLE	TOO LOW

17. CROTCH 4:

--------1------------2------------3------------4------------5--------

TOO HIGH	TOO HIGH BUT ACCEPTABLE	JUST RIGHT	TOO LOW BUT ACCEPTABLE	TOO LOW

18. **Rate the extent that <u>you feel</u> your performance was affected by this glove (compared to bare hand performance):**

THIS GLOVE:

--------1---------------2---------------3---------------4---------------5--------

EXTREMELY DEGRADED MY PERFORMANCE	DEGRADED MY PERFORMANCE A LOT	DEGRADED MY PERFORMANCE A LITTLE	HAD NO EFFECT ON MY PERFORMANCE	ENHANCED MY PERFORMANCE

19. **Rate the comfort of this glove:**

--------1---------------2---------------3---------------4---------------5--------

UNCOMFORTABLE — COMFORTABLE

Please feel free to add comments on the fit and function of the glove:

____

____

____

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)

DEFENCE RESEARCH ESTABLISHMENT OTTAWA
Department of National Defence
Ottawa, Ontario, Canada K1A 0Z4

2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable)

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title.)

FUNCTIONAL FIT EVALUATION TO DETERMINE OPTIMAL EASE REQUIREMENTS IN CHEMICAL PROTECTIVE GLOVES (U)

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

TREMBLAY-LUTTER, Julie F., and WEIHRER, Sylvia J.

5. DATE OF PUBLICATION (month and year of publication of document)

November 1995

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)

6b. NO. OF REFS (total cited in document)

6. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Report

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
Box 4000
Medicine Hat, Alberta, Canada T1A 8K6

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

6fa12

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DRES Report No.

10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availabilty (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both offical languages unless the text is bilingual).

A functional fit evaluation of the Canadian Forces (CF) chemical protective lightweight glove was undertaken in order to quantify the amount of ease required within the glove for optimal functional fit. The results demonstrated that a negative ease in glove digit length of 0.35 cm and a negative ease in glove digit girth of 0.19 cm provided optimal functional fit; while a positive ease of 1.75 cm in glove palm girth was optimal. It was concluded that anthropometric data should not be directly translated into glove design dimensions. Modification of the specifications from hand dimensions, which incorporates consideration of ease, must occur in order to develop gloves which enable effective function and provide a comfortable fit.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

IMPERMEABLE PROTECTIVE GLOVES

EASE

FIT

DEXTERITY

COMFORT

DESIGN